REPORT #
RRTAC 89-3

Efficiency of Activated Charcoal for Inactivation of Bromacil and Tebuthiuron Residues in Soil

Heritage Fund

Alberta

LAND CONSERVATION AND
RECLAMATION COUNCIL
Reclamation Research
Technical Advisory Committee

Alberta's Reclamation Research Program

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To assist with the development and administration of the research program, the Council appointed the inter-departmental Reclamation Research Technical Advisory Committee (RRTAC). The Committee consists of eight members representing the Alberta Departments of Agriculture, Energy, Forestry, Lands and Wildlife, and Environment, and the Alberta Research Council. The Committee updates research priorities, reviews research proposals, organizes workshops, and otherwise acts as the coordinating body for reclamation research in Alberta.

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RRTAC 89-3

EFFICIENCY OF ACTIVATED CHARCOAL FOR INACTIVATION OF BROMACIL AND TEBUTHIURON RESIDUES IN SOIL

by

M.P. Sharma

Prepared for

The Oil and Gas Reclamation Research Program
ALBERTA LAND CONSERVATION AND RECLAMATION COUNCIL
(Reclamation Research Technical Advisory Committee)

1989

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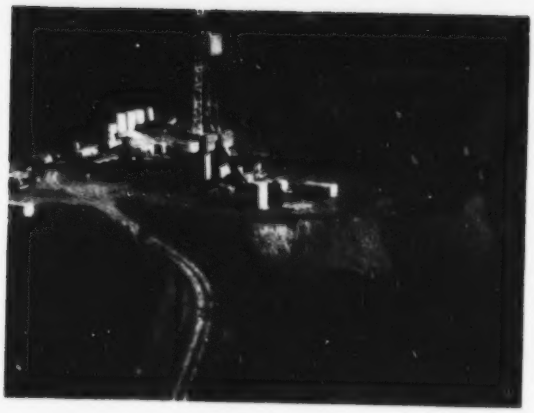
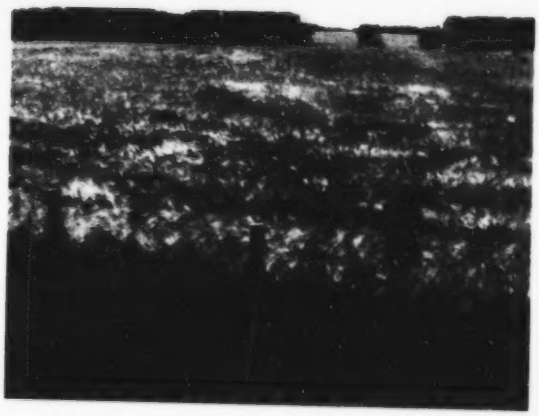
Oil and Gas Reclamation Research Program





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DISCLAIMER

This report is intended to provide government and industry staff with up-to-date technical information to assist in the preparation and review of Development and Reclamation Approvals, and development of guidelines and operating procedures. This report is also available to the public so that interested individuals similarly have access to the most current information on land reclamation topics.

The opinions, findings, conclusions, and recommendations expressed in this report are those of the author(s) and do not necessarily reflect the views of government or industry. Mention of trade names or commercial products does not constitute endorsement, or recommendation for use, by government or industry.

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ABSTRACT

A greenhouse study was conducted to investigate the efficiency of activated charcoal (hereafter referred to as charcoal) for inactivation of bromacil and tebuthiuron residues in soil. The influence of factors such as herbicide:charcoal concentration ratio, soil texture, organic matter content, soil moisture and the time interval between charcoal incorporation and plant establishment was evaluated. Oats (Avena sativa L.) were used as a bioassay species to assess the phytotoxicity of bromacil and tebuthiuron residues.

Both herbicides were more phytotoxic to oats when applied to sand or a mixture of soil+sand (1:1, w/w) as compared to a sandy clay loam soil. Charcoal, when incorporated at rates up to 400 ppm in sand, soil or soil+sand mixture, was not phytotoxic to oats. Incorporation of charcoal at rates ranging from 100 to 400 times the herbicide concentrations (0.2, 0.8 and 2.0 ppm) protected oats, to varying degrees, from bromacil and tebuthiuron injury. The level of protection was dependant upon the ratio of herbicide to charcoal concentrations and two main soil characterstics, namely the organic matter and clay contents. In general, nearly complete protection was achieved when the herbicide to activated charcoal ratio was 1:200 or more. The amount of charcoal required for inactivation of herbicide residues in sand (without clay or organic matter) was less than that required for soil or soil+sand mixture.

Oats suffered more injury from bromacil or tebuthiuron residues when the plants were grown in soil maintained at field capacity (30% soil moisture content) as compared to plants grown in

soil where moisture levels were cycled between 22.5% or 15.0% (wilting point) and field capacity. Protection of oat plants from herbicide injury by charcoal, especially at the lower herbicide:charcoal concentration ratios, was slightly better under the lower moisture regimes than at the high moisture regime. This difference may be due to an increased activity of bromacil and tebuthiuron under optimum moisture conditions rather than to a direct effect of low moisture regimes on the efficiency of activated charcoal on herbicide inactivation.

Protection of oats from bromacil or tebuthiuron injury improved as the time interval between charcoal incorporation and the seeding of oats increased from 0 to 1, and 2 weeks or more. A time interval of at least one week was required for optimum binding of bromacil or tebuthiuron residues in soil by charcoal applied at a ratio of 1:100 (herbicide:charcoal concentration). However, a shorter interval may be adequate at ratios of more than 1:100. Thus, seeding immediately after charcoal incorporation at 1:400 ratio was adequate for the protection of oats from herbicide injury.

It is concluded from the results of this study that charcoal at ratios of 1:200 or more (herbicide:charcoal concentrations) can be used effectively to inactivate bromacil and tebuthiuron residues in soil. The efficiency of charcoal is dependent upon the ratio of herbicide:charcoal concentrations, soil characteristics (clay and organic matter contents and moisture level) and the time interval between charcoal incorporation and plant establishment.

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1. INTRODUCTION

Soil sterilants, residual herbicides that render the treated soil unfit for plant growth for relatively long periods of time, were commonly used in Alberta for total vegetation control on oil and gas well sites, rights-of-way and other industrial areas. Such vegetation control measures are required to reduce fire hazards and improve aesthetic appearance. The sterilant-treated areas can remain devoid of vegetation for many years, depending upon the type and rate of soil sterilant used and the climatic conditions. Furthermore, it was a common practice to use more than the recommended rates in a single application or many applications of these chemicals for achieving long-term vegetation control (personal communication, Industrial Vegetation Management Association of Alberta). Bromacil and tebuthiuron (Figure 1) are commonly used soil sterilants in Alberta (Dallas 1987).

Once an area is treated with a soil sterilant, it may take several years before the treated site is restored to its original capability. The site also becomes a source of contamination through surface runoff and wind dispersion of soil sterilants onto the adjoining untreated land. In Alberta, the problems related to soil sterilants are on the increase as more oil and gas lease sites are abandoned due to marginal value of wells (Dallas 1987). The seriousness of the problem has been identified by various provincial organizations and advisory committees including:

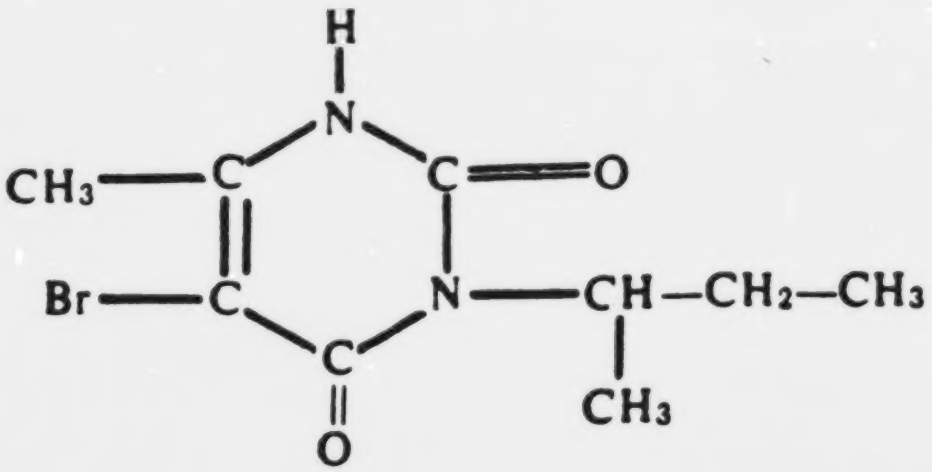
1. Industrial Vegetation Management Association of Alberta (IVMAA)

Bromacil

Chemical Name: 5-bromo-6-methyl-3-(1-methylpropyl)uracil

Trade Names: CALMIX®, HYVAR®

Structure:



Tebuthiuron

Chemical Name: N-[5-(1,1-dimethylethyl)-1,3,4-thiadiazol-2-yl]-N,N′-dimethylurea

Trade Name: SPIKE®

Structure:

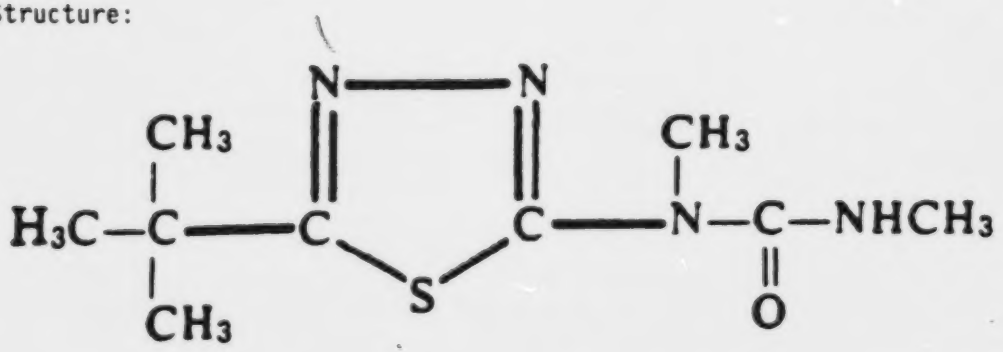


Figure 1. Chemical name, trade name(s) and structure of bromacil and tebuthiuron.

2. Alberta Soil Advisory Committee
3. Alberta Weed Advisory Committee
4. Pesticides Management Branch, Alberta Environment
5. Soil Sterilants Workshop (May 1986) organized by the Research Management Division, Alberta Environment
6. Alberta Environmental Centre; increased number of submissions, related to soil sterilant-contaminated soils, to the Centre's Chemical Damage Diagnostic Service.

The Land Surface Conservation and Reclamation Act of Alberta (Anonymous 1984) governs the reclamation of land affected by soil sterilants in the province. The Act requires that soils contaminated with residual herbicides (soil sterilants) be brought back to the level of capability equivalent to that prior to the contamination.

There is a lack of adequate information in the scientific literature on the technology to reclaim soils containing soil sterilant(s). Herbicides can be removed from soil solution and made unavailable or less available to plants by the addition of adsorbents (Shea 1985). Thus, the addition of adsorbents is one way of rehabilitating sterilant-affected soils. Activated charcoal, due to its large surface area (600 to 1200 m^2/g), has been shown to strongly adsorb organic molecules including herbicides (Jordan and Smith 1971; Lamoreaux et al. 1989; Shea 1985). Its use for inactivating herbicide residues in soil and reducing injury to sensitive plants has been demonstrated by several workers (Bovey and Miller 1969; Burr et al. 1972; Chandler et al. 1978; Coffey and

Warren 1969; Ogg 1982). It has also been reported that the amount of charcoal required to inactivate herbicide residues in soil and to protect plants from herbicide injury may depend upon the type of herbicide (Shea 1985; Sheets and Harris 1965; Warren 1973), herbicide concentration (Bovey and Miller 1969, Sheets and Harris 1965) and soil texture and organic matter content (Anderson 1968). However, information is lacking on various factors influencing the effectiveness of activated charcoal for inactivation of bromacil and tebuthiuron residues in Alberta soils.

2. OBJECTIVE

The objective of this greenhouse study was to evaluate the efficiency of activated charcoal for inactivation of bromacil and tebuthiuron residues in soil as influenced by:

1. the ratio of herbicide:activated charcoal concentrations,
2. soil texture,
3. soil organic matter content,
4. soil moisture, and
5. the time interval between charcoal incorporation and plant establishment.

3. EXPERIMENTAL DETAILS

Pot experiments, using oats (Avena sativa L.) cv. Random as bioassay plants, were conducted in a greenhouse to study the effects of various factors on the efficiency of activated charcoal for inactivation of bromacil and tebuthiuron residues in soil. Oat was selected as a bioassay test plant because it has a marked sensitivity to these herbicides and is easy to grow (Horowitz 1976).

3.1 GENERAL EXPERIMENTAL PROCEDURES

A Chernozemic Black sandy clay loam (hereafter referred to as soil) from Vegreville, washed silica sand or a mixture of soil+sand (1:1, w/w) were used for growing plants. The characteristics of each growing medium are presented in Table 1. Bromacil (HYVAR X-L, 240g/L) or tebuthiuron (SPIKE, 80% WP) was mixed with each of the media at 0, 0.2, 0.8 and 2.0 ppm active ingredient (w/w), unless stated otherwise. One day later, activated charcoal (60-100 mesh size, NORIT® - trademark of Atlas Chemical Co.*) was mixed in the herbicide-treated soil or sand at 0, 100, 200 and 400 times the concentration of bromacil or tebuthiuron. Charcoal at 0, 100, 200 and 400 ppm (w/w) was also incorporated into soil or sand not treated with herbicides (control treatment). A batter beater "Model 1301" (trademark of Blakerlee Food Service Equipment Inc., Scarborough, Ontario) was used for mixing the herbicides and charcoal in the growing media.

*Obtained from VanWaters & Rogers, Edmonton.

Table 1. Characteristics of the Three Growing Media Used in the Study.

Characteristic	Growing Media		
	Soil*	Sand	Soil+Sand (1:1, w/w)
Texture			
Clay (%)	23	0	11.5
Silt (%)	27	0	13.5
Sand (%)	50	100	75.0
Organic Matter (%)**	8.5	0	4.2
pH***	5.6	6.6	5.7
EC(mS/cm)***	0.8	0.2	0.2
Moisture Content at Field Capacity (%)	30	19	24

* Classified as sandy clay loam.

** Wet oxidation method.

*** Saturated paste method.

A 900 g sample from each of the treated growing medium (575 g for sand) was measured into 1 L plastic containers (0.6 L for sand) without holes. Six oat seeds were planted 1 cm deep in each container. The moisture content in each container was brought to field capacity soon after seeding. After that, the moisture content was maintained between 65 and 100% of field capacity by watering every day or on alternate days as required. The watering was done by weighing each pot to a predetermined weight. All experiments were arranged in a randomized complete block design with four replicates. A total of 10 separate experiments, five each with bromacil and tebuthiuron, were conducted.

The plants were grown in a greenhouse operated at 24-16°C day-night, and supplemented with 16 h light of 275 $\mu E.m^{-2}.s^{-1}$ photon flux from high pressure sodium lamps. One week after planting, seedlings were thinned to three uniform plants in each container.

3.2 FACTORS INFLUENCING THE EFFICIENCY OF ACTIVATED CHARCOAL

To study the effect of soil texture, soil organic matter content and the ratio of herbicide:charcoal concentrations, bromacil or tebuthiuron was mixed in soil, washed silica sand or a mixture of soil+sand (1:1, w/w). The herbicide concentrations were 0, 0.2, 0.8 and 2.0 ppm. Charcoal was incorporated at 0, 100, 200 and 400 times the herbicide concentrations. In experiments involving sand or soil+sand, a solution of 20:20:20 fertilizer was added to bring the nitrogen level to 16 ppm, same as in the unamended soil.

The effect of soil moisture on inactivation of bromacil and tebuthiuron residues was studied by mixing the herbicides in a sandy

clay loam soil at 0 and 0.8 ppm. Charcoal was mixed at 0, 80, 160 and 320 ppm. The moisture content in each container was brought to field capacity (30% soil moisture content) soon after seeding. Three days after seeding, the containers were subjected to three moisture regimes:

1. Plants watered daily to field capacity.
2. Soil moisture cycled between 22.5% and field capacity.
3. Soil moisture cycled between 15% (soil moisture content at wilting point) and field capacity.

To study the effect of time interval between charcoal incorporation and planting of oats, bromacil or tebuthiuron was mixed into the soil at 0 and 0.8 ppm. Charcoal was incorporated at 0, 80 and 320 ppm. Oats were seeded 0, 1, 2, 4 or 6 weeks after the incorporation of the charcoal. After the initial watering to field capacity, the moisture content in each pot was maintained between 65 and 100% of field capacity.

3.3 EVALUATIONS AND DATA ANALYSIS

Plants were visually scored for herbicide injury at weekly intervals on a 0 to 9 scale where 0 = complete kill, 9 = no visible effect. Shoot dry weights were determined four weeks after seeding, unless stated otherwise. The dry weight data were analyzed using factorial analysis of variance (ANOVA).

4. RESULTS AND DISCUSSION

4.1 PHYTOTOXICITY OF BROMACIL AND TEBUTHIURON RESIDUES IN SOIL

Bromacil and tebuthiuron mixed separately into a sandy clay loam soil at 0.2 ppm did not cause injury to oats (Tables 2 and 3; Figure 2). However, at 0.8 and 2.0 ppm, both herbicides resulted in severe injury to, or complete death of, plants after 3 weeks (Tables 2 and 3; Figure 3). The injury symptoms included severe chlorosis (whitening), necrosis and wilting which, in the case of bromacil, started about mid-leaf and then extended to the tip. In the case of tebuthiuron, these symptoms usually started at the leaf tip. The injury symptoms usually were noticeable in 7 to 10 days after seeding and were fully developed by 3 weeks after seeding.

Both herbicides were more phytotoxic when applied to sand or to a mixture of soil+sand than to the soil (Tables 4 to 7; Figures 2 to 6). For example, 0.2 ppm bromacil (Figure 4) or tebuthiuron completely killed the oat plants when incorporated into sand. Also, the herbicide injury symptoms appeared quicker on plants grown in sand than the plants grown in soil. The extent of herbicide injury to oat plants grown in soil+sand mixture was intermediate compared to the plants grown in sand or soil alone.

The reduced activity of bromacil and tebuthiuron in soil and soil+sand mixture, as compared to sand alone, can be attributed largely to adsorption of these herbicides to the organic matter and clay constituents in soil (Calvert 1980). The organic matter and clay contents of soil and soil+sand mixture were 9.5% and 23%, and 4.2% and 11.5%, respectively (Table 1). None of these colloidal constituents were present in sand.

Table 2. Effect of activated charcoal on the inactivation of bromacil residues in soil as measured by an oat bioassay. Shoot dry weights were determined four weeks after seeding.

Herbicide (ppm)	Activated Charcoal (ppm)	Herbicide: Charcoal Ratio	Injury Rating		Shoot Dry Weight	
			1 wk	3 wks	g/pot	±SE
0	0		9	9	1.38	0.09
0	100		9	9	1.52	0.15
0	200		9	9	1.52	0.15
0	400		9	9	1.43	0.11
0.2	0	0	9	9	1.26	0.07
0.2	20	100	9	9	1.45	0.14
0.2	40	200	9	9	1.47	0.11
0.2	80	400	9	9	1.37	0.08
0.8	0	0	9	0	0.07	0.00
0.8	80	100	9	2	0.10	0.01
0.8	160	200	9	5	0.42	0.16
0.8	320	400	9	9	1.10	0.15
2.0	0	0	8	0	0.04	0.01
2.0	200	100	9	0	0.06	0.01
2.0	400	200	9	0	0.07	0.00
2.0	800	400	9	9	1.51	0.11
ANOVA						
Herbicide					**	
Activated Charcoal					**	
Herbicide x Activated Charcoal					**	

**Significant at P = 0.01.

Table 3. Effect of activated charcoal on the inactivation of tebuthiuron residues in soil as measured by an oat bioassay. Shoot dry weights were determined four weeks after seeding.

Herbicide (ppm)	Activated Charcoal (ppm)	Herbicide: Charcoal Ratio	Injury Rating 1 wk	Injury Rating 3 wks	Shoot Dry Weight g/pot	Shoot Dry Weight ±SE
0	0		9	9	1.26	0.08
0	100		9	9	1.31	0.10
0	200		9	9	1.23	0.12
0	400		9	9	1.27	0.05
0.2	0	0	9	9	1.31	0.07
0.2	20	100	9	9	1.30	0.09
0.2	40	200	9	9	1.23	0.12
0.2	80	400	9	9	1.18	0.10
0.8	0	0	9	2	0.12	0.01
0.8	80	100	9	5	0.41	0.04
0.8	160	200	9	8	0.95	0.08
0.8	320	400	9	9	1.27	0.11
2.0	0	0	8	0	0.04	0.00
2.0	200	100	9	1	0.06	0.01
2.0	400	200	9	5	0.48	0.06
2.0	800	400	9	9	1.16	0.11
ANOVA						
Herbicide					**	
Activated Charcoal					**	
Herbicide x Activated Charcoal					**	

**Significant at P = 0.01.

Table 4. Effect of activated charcoal on the inactivation of bromacil residues in sand as measured by an oat bioassay. Shoot dry weights were determined three weeks after seeding.

Herbicide (ppm)	Activated Charcoal (ppm)	Herbicide: Charcoal Ratio	Injury Rating		Shoot Dry Weight	
			1 wk	3 wks	g/pot	±SE
0	0		9	9	0.47	0.04
0	100		9	9	0.46	0.03
0	200		9	9	0.46	0.04
0	400		9	9	0.54	0.03
0.2	0	0	9	0	0.03	0.00
0.2	20	100	9	0	0.03	0.00
0.2	40	200	9	0	0.04	0.00
0.2	80	400	9	9	0.45	0.06
0.8	0	0	8	0	0.03	0.00
0.8	80	100	9	0	0.04	0.01
0.8	160	200	9	9	0.40	0.04
0.8	320	400	9	9	0.54	0.04
2.0	0	0	8	0	0.04	0.00
2.0	200	100	9	0	0.04	0.00
2.0	400	200	9	9	0.51	0.03
2.0	800	400	9	9	0.54	0.03

ANOVA

Herbicide	**
Activated Charcoal	**
Herbicide x Activated Charcoal	**

**Significant at P = 0.01.

Table 5. Effect of activated charcoal on the inactivation of tebuthiuron residues in sand as measured by an oat bioassay. Shoot dry weights were determined three weeks after seeding.

Herbicide (ppm)	Activated Charcoal (ppm)	Herbicide: Charcoal Ratio	Injury Rating 1 wk	Injury Rating 3 wks	Shoot Dry Weight g/pot	Shoot Dry Weight ±SE
0	0		9	9	0.48	0.02
0	0		9	9	0.55	0.02
0	0		9	9	0.48	0.03
0	0		9	9	0.56	0.03
0.2	0	0	9	0	0.03	0.0
0.2	20	100	9	0	0.03	0.0
0.2	40	200	9	0	0.03	0.0
0.2	80	400	9	9	0.48	0.03
0.8	0	0	8	0	0.03	0.0
0.8	80	100	9	0	0.03	0.0
0.8	160	200	9	9	0.33	0.03
0.8	320	400	9	9	0.49	0.03
2.0	0	0	8	0	0.03	0.0
2.0	200	100	9	0	0.04	0.0
2.0	400	200	9	9	0.58	0.03
2.0	800	400	9	9	0.50	0.03
ANOVA						
Herbicide					**	
Activated Charcoal					**	
Herbicide x Activated Charcoal					**	

**Significant at P = 0.01.

Table 6. Effect of activated charcoal on the inactivation of bromacil residues in a mixture of soil and sand (1:1, w/w) as measured by an oat bioassay. Shoot dry weights were determined three weeks after seeding.

Herbicide (ppm)	Activated Charcoal (ppm)	Herbicide: Charcoal Ratio	Injury Rating		Shoot Dry Weight	
			1 wk	3 wks	g/pot	±SE
0	0		9	9	1.65	0.15
0	100		9	9	1.65	0.07
0	200		9	9	1.65	0.10
0	400		9	9	1.65	0.08
0.2	0	0	9	8	1.07	0.04
0.2	20	100	9	9	1.40	0.04
0.2	40	200	9	0	1.41	0.11
0.2	80	400	9	9	1.61	0.15
0.8	0	0	8	0	0.04	0.01
0.8	80	100	9	0	0.07	0.01
0.8	160	200	9	2	0.29	0.06
0.8	320	400	9	9	1.40	0.12
2.0	0	0	8	0	0.03	0.00
2.0	200	100	9	0	0.06	0.01
2.0	400	200	9	6	0.79	0.05
2.0	800	400	9	9	1.51	0.16

ANOVA

Herbicide	**
Activated Charcoal	**
Herbicide x Activated Charcoal	**

**Significant at P = 0.01.

Table 7. Effect of activated charcoal on the inactivation of tebuthiuron residues in a mixture of soil and sand (1:1, w/w) as determined by an oat bioassay. Shoot dry weights were determined four weeks after seeding.

Herbicide (ppm)	Activated Charcoal (ppm)	Herbicide: Charcoal Ratio	Injury Rating 1 wk	Injury Rating 3 wks	Shoot Dry Weight g/pot	Shoot Dry Weight ±SE
0	0		9	9	1.93	0.08
0	100		9	9	1.97	0.10
0	200		9	9	1.82	0.08
0	400		9	9	1.76	0.09
0.2	0	0	9	9	1.47	0.06
0.2	20	100	9	9	1.52	0.03
0.2	40	200	9	9	1.49	0.04
0.2	80	400	9	9	1.77	0.08
0.8	0	0	9	0	0.04	0.01
0.8	80	100	9	0	0.06	0.01
0.8	160	200	9	1	0.13	0.01
0.8	320	400	9	9	1.34	0.02
2.0	0	0	8	0	0.03	0.00
2.0	200	100	9	0	0.04	0.00
2.0	400	200	9	2	0.29	0.01
2.0	800	400	9	9	1.52	0.04

ANOVA	
Herbicide	**
Activated Charcoal	**
Herbicide x Activated Charcoal	**

**Significant at P = 0.01.

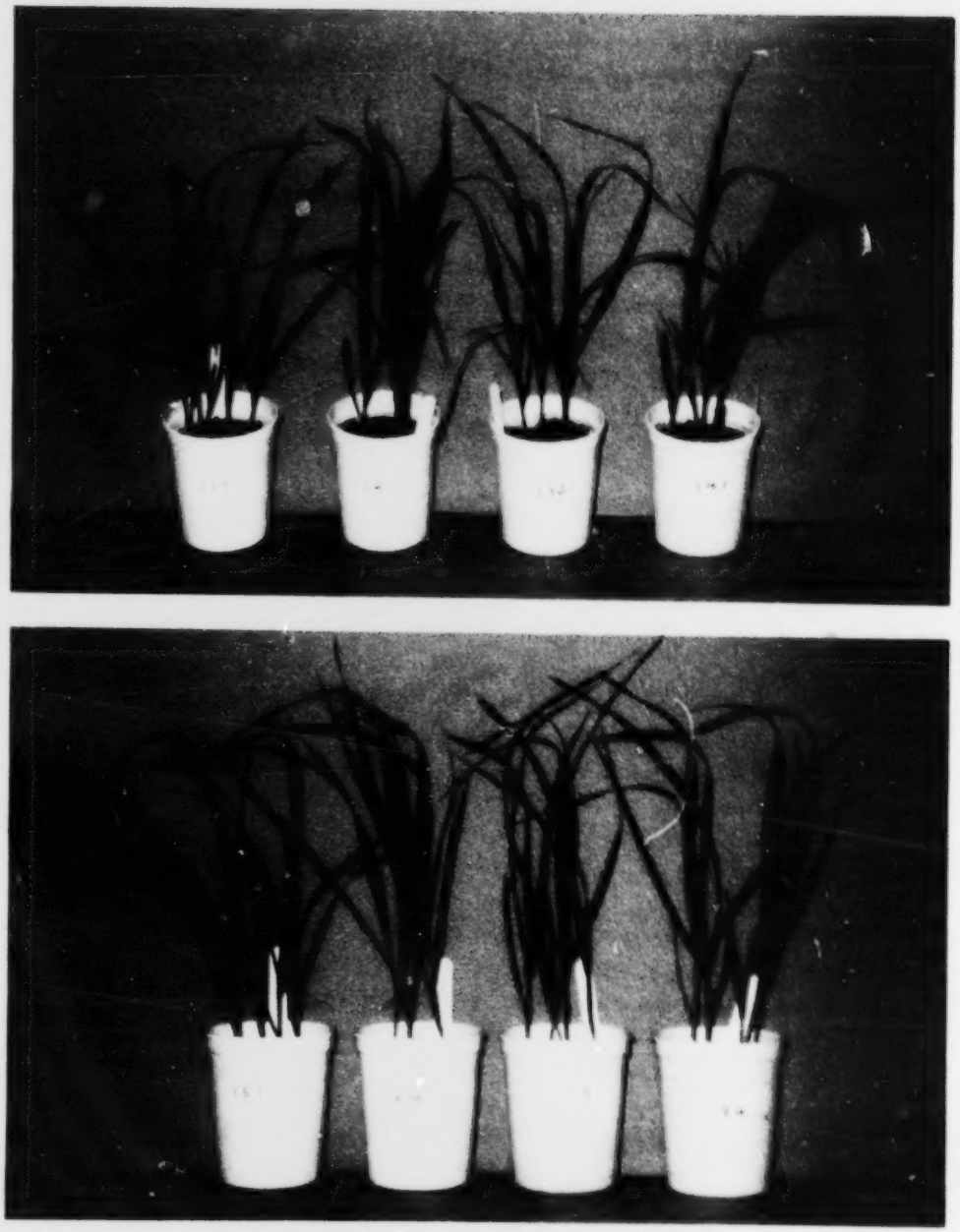


Figure 2. Photographs of plants grown in soil, untreated (upper) and treated with 0.2 ppm bromacil (lower). Activated charcoal was mixed in (left to right) at 0, 100, 200 and 400 times the herbicide concentration.

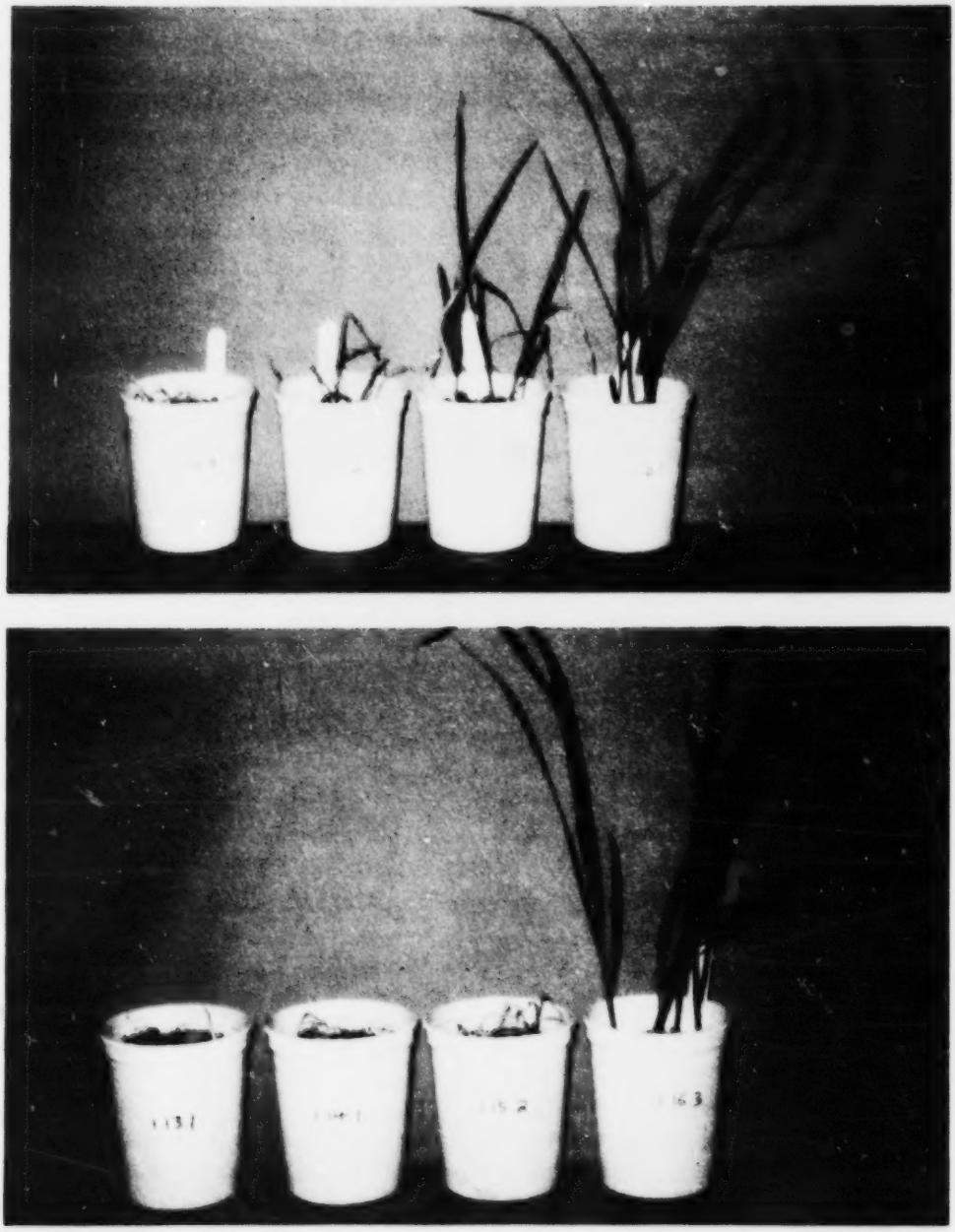


Figure 3. Photographs of plants grown in soil treated with bromacil at 0.8 ppm (upper) and 2.0 ppm (lower). Activated charcoal was mixed in (left to right) at 0, 100, 200 and 400 times the herbicide concentration.

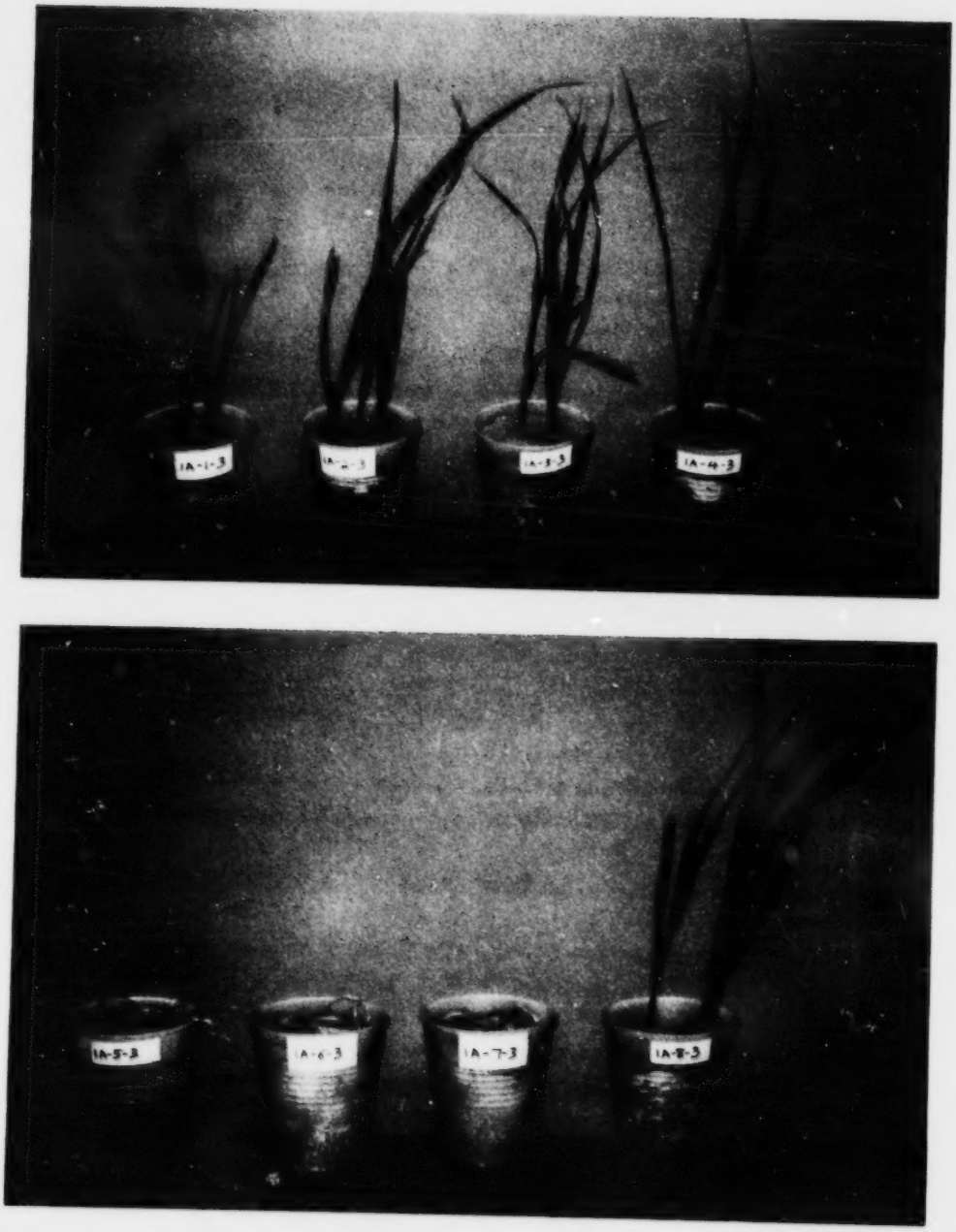


Figure 4. Photographs of plants grown in sand, untreated (upper) and treated with 0.2 ppm (lower) bromacil. Activated charcoal was mixed in (left to right) at 0, 100, 200 and 400 times the herbicide concentration.

Figure 5. Photographs of plants grown in sand, treated with bromacil at 0.8 ppm (upper) and 2.0 ppm (lower). Activated charcoal was mixed in (left to right) at 0, 100, 200 and 400 times the herbicide concentration.

Figure 6. Photographs of plants grown in a mixture of soil+sand treated with bromacil at 0.2 ppm (upper), 0.8 ppm (middle) and 2.0 ppm (lower). Activated charcoal was mixed in (left to right) at 0, 100, 200 and 400 times the herbicide concentration.

4.2 INACTIVATION OF HERBICIDE RESIDUES BY ACTIVATED CHARCOAL

Activated charcoal at rates up to 400 ppm in soil, sand or soil+sand mixture was not phytotoxic when incorporated without the herbicides (Tables 2 to 7). The incorporation of activated charcoal at rates ranging from 100 to 400 times the herbicide concentrations protected oats, to varying degrees, from bromacil and tebuthiuron injury (Figures 2-6).

4.3 FACTORS AFFECTING THE EFFICIENCY OF ACTIVATED CHARCOAL

4.3.1 Ratio of Herbicide:Charcoal Concentrations

The level of protection of oats from bromacil or tebuthiuron injury due to charcoal varied with the ratio of herbicide to charcoal concentrations (Tables 2 to 7; Figures 2 to 6). In soil or soil+sand mixture, nearly complete protection was achieved when the ratio of herbicide to charcoal concentrations was 1:400. In sand, on the other hand, oats were protected when this ratio was 1:200 or more, especially at the 0.8 and 2.0 ppm herbicide concentrations. It also appears that for effective inactivation of herbicide residues, not only a certain ratio of herbicide:charcoal concentrations is required, but a minimum amount of charcoal is essential. For example, in sand containing 0.2 ppm bromacil or tebuthiuron, charcoal at 100 or 200 times the herbicide concentration (20 and 40 ppm charcoal) was not sufficient for providing adequate protection of oats from herbicide injury (Tables 4 and 5).

The ratios of herbicide:charcoal concentration required for the protection of oats from bromacil and tebuthiuron are similar

to those reported in the literature for various herbicides and plant species. Ahrens (1965) reported that a herbicide:activated charcoal ratio of 200:1 was required to protect moderately sensitive crops against simazine at soil residues of 1 lb/acre. At higher levels of residue or for protecting very sensitive crops, ratio of 1:400 was required. Anderson (1968) observed that the soil organic matter content and the efficiency of incorporation influenced the amount of charcoal required with a range of 200:1 to 400:1 of charcoal to simazine. Lamoreaux et al (1989) reported that norflurazon:charcoal ratios of 100:1 to 300:1 completely prevented norflurazon injury to various crops.

4.3.2 Soil Characteristics

The amount of activated charcoal required for inactivation of bromacil and tebuthiuron residues was dependent upon the characteristics of the growing media. For example, 400 ppm charcoal provided complete protection to oats grown in sand, but no protection or only partial protection to oats grown in soil or a soil+sand mixture treated with 2.0 ppm bromacil or tebuthiuron (Figure 7).

The difference in the amount of activated charcoal required for inactivation of bromacil and tebuthiuron residues in soil, sand and a soil+sand mixture could be explained theoretically on the basis of relatively stronger binding of herbicide molecules by activated charcoal as compared to organic matter and clay constituents (Coffey and Warren 1969; Jordan and Smith 1971). The herbicide molecules when mixed in sand, remain in solution and will

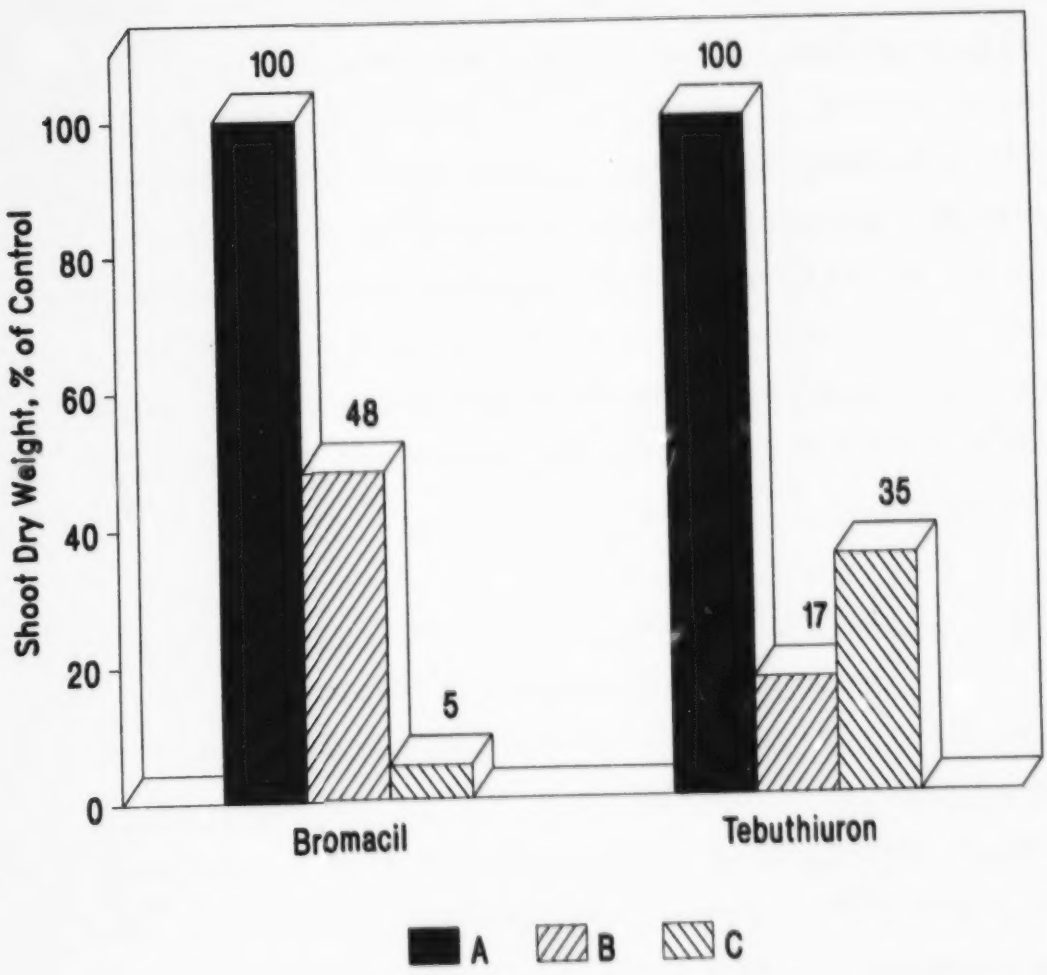


Figure 7. Effect of activated charcoal (400 ppm) on the inactivation of 2.0 ppm bromacil and tebuthiuron in sand (A), soil+sand mixture (B) and soil (C), as measured by an oat bioassay Data are represented as percent of mean dry weight of all controls (0 ppm herbicide and 0 to 400 ppm activated charcoal).

be available for root uptake by plants. The incorporation of activated charcoal strongly adsorbs the herbicide molecule(s) and will render them unavailable for root uptake by plants. On the other hand, when bromacil or tebuthiuron are mixed in soil or soil+sand mixture a portion of the herbicide molecules will be adsorbed on to organic matter and clay constituents. Incorporation of activated charcoal to soil or soil+sand mixture will adsorb only the remaining unadsorbed herbicide molecules. Through the desorption process, herbicide molecules adsorbed on to the soil constituents are released into soil solution (Schmidt and Pestemer 1980) and become available to plants grown in soil or a soil+sand mixture.

4.3.3 Soil Moisture

Injury to oat plants from bromacil or tebuthiuron decreased as the soil moisture level decreased from daily watering to field capacity to moisture levels cycled between 22.5% or 15% and field capacity (Tables 8 and 9). Also, the appearance of herbicide injury symptoms was delayed under lower soil moisture regimes. The protection of oat plants from herbicide injury by activated charcoal, especially at the lower herbicide:charcoal concentration ratios, was slightly better under the lower soil moisture regimes than under the high soil moisture regime. This difference may be due to an increased activity of bromacil and tebuthiuron under optimum moisture conditions (such as in pots watered daily to field capacity) rather than to a direct effect of low moisture regimes on the efficiency of activated charcoal for herbicide inactivation. In

Table 8. Effect of soil moisture on the inactivation of bromacil residues in soil by activated charcoal as measured by an oat bioassay. Shoot dry weights were determined four weeks after seeding.

Herbicide (ppm)	Activated Charcoal (ppm)	Soil Moisture	Injury Rating 2 wks	Injury Rating 4 wks	Shoot Dry Weight g/pot	Shoot Dry Weight ±SE
0	0	F.C.	9	9	2.91	0.10
0.8	0	F.C.	1	0	0.11	0.01
0.8	80	F.C.	4	0	0.19	0.02
0.8	160	F.C.	9	6	1.31	0.09
0.8	320	F.C.	9	9	2.74	0.07
0	0	22.5%-F.C.	9	9	2.21	0.11
0.8	0	22.5%-F.C.	1	0	0.11	0.01
0.8	80	22.5%-F.C.	9	0	0.17	0.02
0.8	160	22.5%-F.C.	9	6	1.34	0.08
0.8	320	22.5%-F.C.	9	9	2.07	0.11
0	0	15%-F.C.	9	9	1.10	0.07
0.8	0	15%-F.C.	2	0	0.13	0.01
0.8	80	15%-F.C.	8	1	0.32	0.02
0.8	160	15%-F.C.	9	7	0.98	0.06
0.8	320	15%-F.C.	9	9	1.18	0.07
ANOVA						
Activated Charcoal					**	
Soil Moisture					**	
Activated Charcoal x Soil Moisture					**	

**Significant at P = 0.01

Table 9. Effect of soil moisture on the inactivation of tebuthiuron residues in soil by activated charcoal as measured by an oat bioassay. Shoot dry weights were determined four weeks after seeding.

Herbicide (ppm)	Activated Charcoal (ppm)	Soil Moisture	Injury Rating 2 wks	Injury Rating 4 wks	Shoot Dry Weight g/pot	Shoot Dry Weight ±SE
0	0	F.C.	9	9	2.24	0.07
0.8	0	F.C.	2	0	0.15	0.01
0.8	80	F.C.	6	1	0.26	0.03
0.8	160	F.C.	9	3	0.93	0.10
0.8	320	F.C.	9	8	1.84	0.12
0	0	22.5%-F.C.	9	9	1.95	0.11
0.8	0	22.5%-F.C.	3	0	0.15	0.02
0.8	80	22.5%-F.C.	7	1	0.27	0.03
0.8	160	22.5%-F.C.	9	4	1.09	0.06
0.8	320	22.5%-F.C.	9	8	1.70	0.10
0	0	15%-F.C.	9	9	1.41	0.10
0.8	0	15%-F.C.	9	1	0.20	0.02
0.8	80	15%-F.C.	9	1	0.35	0.03
0.8	160	15%-F.C.	9	5	0.97	0.04
0.8	320	15%-F.C.	9	9	1.27	0.08

ANOVA

Activated Charcoal	**
Soil Moisture	**
Activated Charcoal x Soil Moisture	**

**Significant at P = 0.01

this study, all the pots were initially watered to field capacity (30% moisture content) and it took one week or more for the soil moisture content to decrease to 22.5% or 15%. Since a time interval of 1 week between charcoal incorporation and seeding oats may be sufficient for the optimum efficiency of activated charcoal for the inactivation of bromacil or tebuthiuron residues in soil (discussed in Section 4.3.4), the differences in the soil moisture regimes after 1 week may not be important.

4.3.4 Time Interval Between Charcoal Incorporation and Seeding Oats

The overall effect of time interval between charcoal incorporation and seeding oats was not significant (Tables 10 and 11). However, the interaction between time interval and charcoal rates was significant. Thus, at the 80 ppm rate of activated charcoal (100 times the herbicide concentration), the protection of oats from bromacil or tebuthiuron injury improved as the time interval increased from 0 to 1 and 2, 4 or 6 weeks (Tables 10 and 11; Figures 8, 9 and 10). Also, there was no difference between the time intervals of 2, 4 and 6 weeks. From the results of these experiments it is apparent that: 1) a time interval of 1 to 2 weeks is required for maximum inactivation of bromacil or tebuthiuron residues in soil by charcoal applied at suboptimal rates, for example, at a ratio of 1:100 (herbicide:charcoal), and 2) a shorter interval is adequate at ratios of more than 1:100. Thus, at a ratio of 1:400, seeding immediately after charcoal incorporation was adequate for the protection of oats from bromacil or tebuthiuron injury.

Table 10. Effect of time interval between incorporation of activated charcoal and seeding on the inactivation of bromacil residues in soil as measured by an oat bioassay. Shoot dry weights were determined four weeks after seeding.

Herbicide (ppm)	Activated Charcoal (ppm)	Time Interval (weeks)	Injury Rating		Shoot Dry Weight	
			3 wks	4 wks	g/pot	±SE
0	0	0	9	9	1.74	0.10
0.8	0	0	4	0	0.08	0.01
0.8	80	0	8	1	0.10	0.01
0.8	320	0	9	9	1.69	0.20
0	0	1	9	9	1.70	0.20
0.8	0	1	5	0	0.07	0.01
0.8	80	1	8	1	0.19	0.02
0.8	320	1	9	9	1.52	0.18
0	0	2	9	9	1.57	0.15
0.8	0	2	6	0	0.09	0.01
0.8	80	2	9	5	0.39	0.05
0.8	320	2	9	9	1.44	0.10
0	0	4	9	9	1.67	0.13
0.8	0	4	6	0	0.10	0.01
0.8	80	4	9	5	0.34	0.04
0.8	320	4	9	9	1.43	0.10
0	0	6	9	9	1.40	0.10
0.8	0	6	6	0	0.09	0.01
0.8	80	6	9	5	0.35	0.05
0.8	320	6	9	9	1.44	0.10

ANOVA

Activated Charcoal	**
Time Interval	NS
Activated Charcoal x Time Interval	*

* Significant at P = 0.05
**Significant at P = 0.01

Table 11. Effect of time interval between incorporation of activated charcoal and seeding on the inactivation of tebuthiuron residues in soil as measured by an oat bioassay. Shoot dry weights were determined four weeks after seeding.

Herbicide (ppm)	Activated Charcoal (ppm)	Time Interval (weeks)	Injury Rating 3 wks	Injury Rating 4 wks	Shoot Dry Weight g/pot	Shoot Dry Weight ±SE
0	0	0	9	9	1.71	0.09
0.8	0	0	7	1	0.11	0.01
0.8	80	0	9	5	0.36	0.05
0.8	320	0	9	9	1.34	0.12
0	0	1	9	9	1.72	0.17
0.8	0	1	9	2	0.15	0.02
0.8	80	1	9	5	0.63	0.07
0.8	320	1	9	9	1.31	0.04
0	0	2	9	9	1.62	0.06
0.8	0	2	9	2	0.22	0.02
0.8	80	2	9	6	0.84	0.06
0.8	320	2	9	9	1.44	0.15
0	0	4	9	9	1.38	0.20
0.8	0	4	9	2	0.22	0.02
0.8	80	4	9	6	0.65	0.10
0.8	320	4	9	9	1.30	0.07
0	0	6	9	9	1.46	0.19
0.8	0	6	9	2	0.29	0.02
0.8	80	6	9	6	0.77	0.04
0.8	320	6	9	9	1.39	0.05

ANOVA

Activated Charcoal	**
Time Interval	NS
Activated Charcoal x Time Interval	*

* Significant at P = 0.05
**Significant at P = 0.01

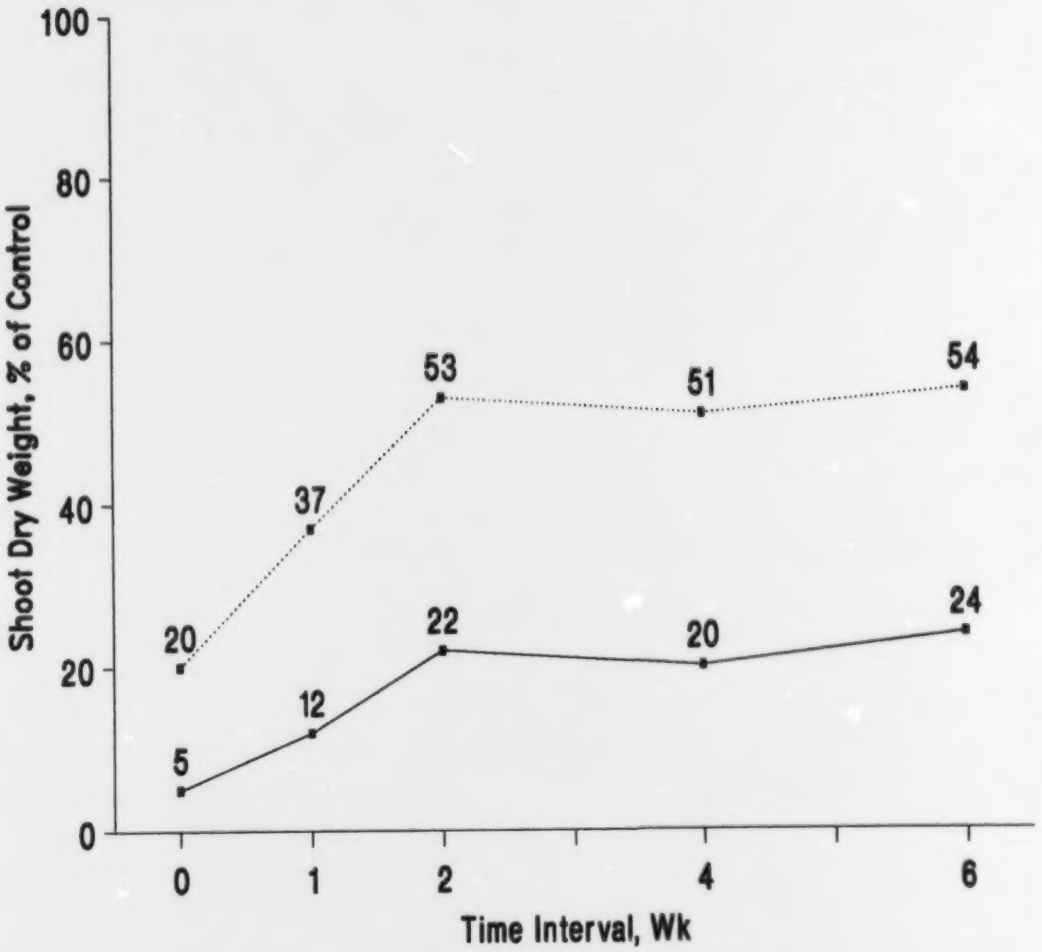


Figure 8. Effect of time interval between incorporation of activated charcoal (80 ppm) and seeding oats on the inactivation of bromacil (solid line) and tebuthiuron (broken line) residues (0.8 ppm) in soil. Data presented as percent of control (0 ppm herbicide and 0 ppm activated charcoal).

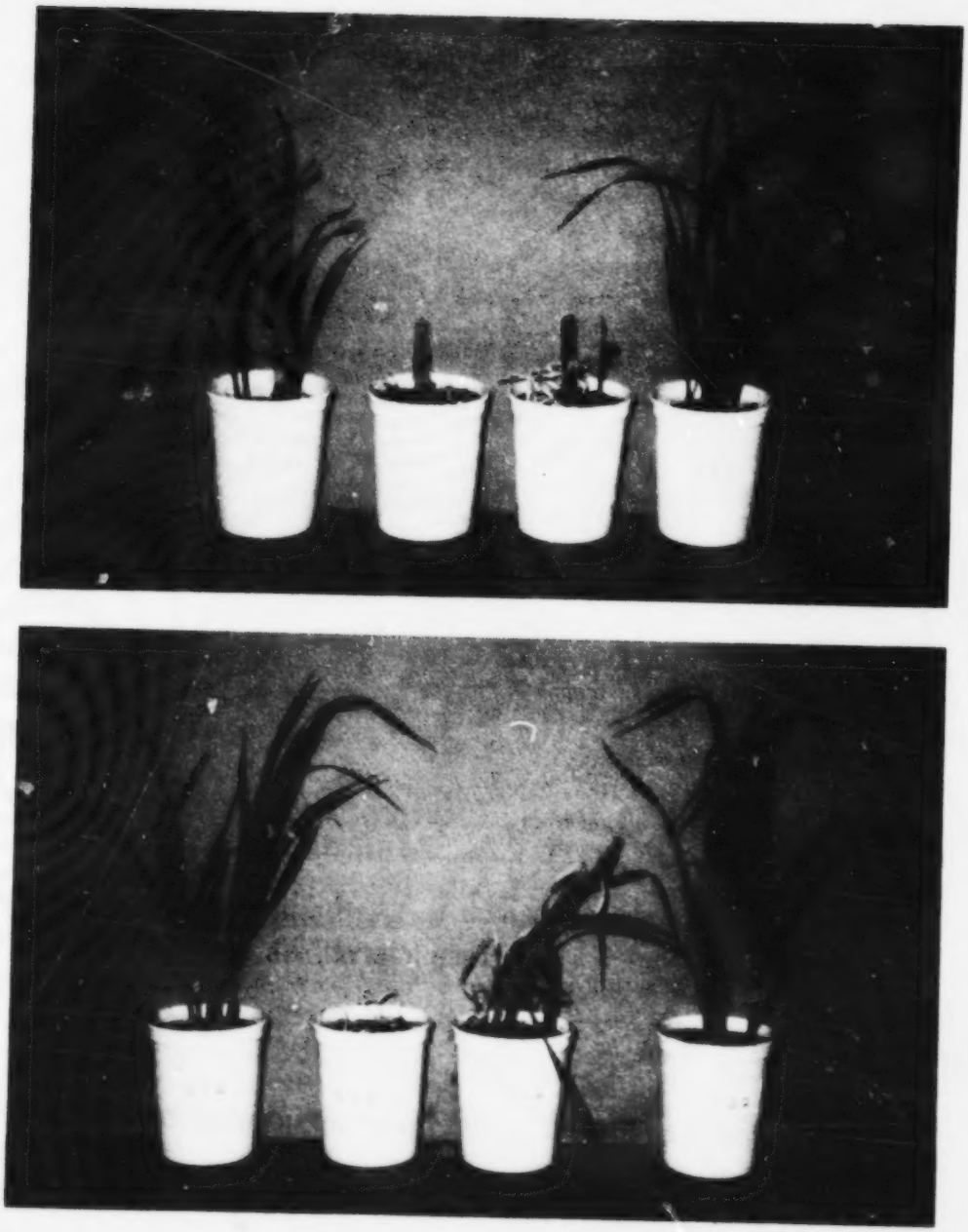


Figure 9. Photographs of oat plants grown in soil treated with 0.8 ppm bromacil and activated charcoal at (left to right) 0, 100, 200 and 400 times the herbicide concentration. Oats were seeded 1 week (upper) and 2 weeks (lower) after activated charcoal incorporation.

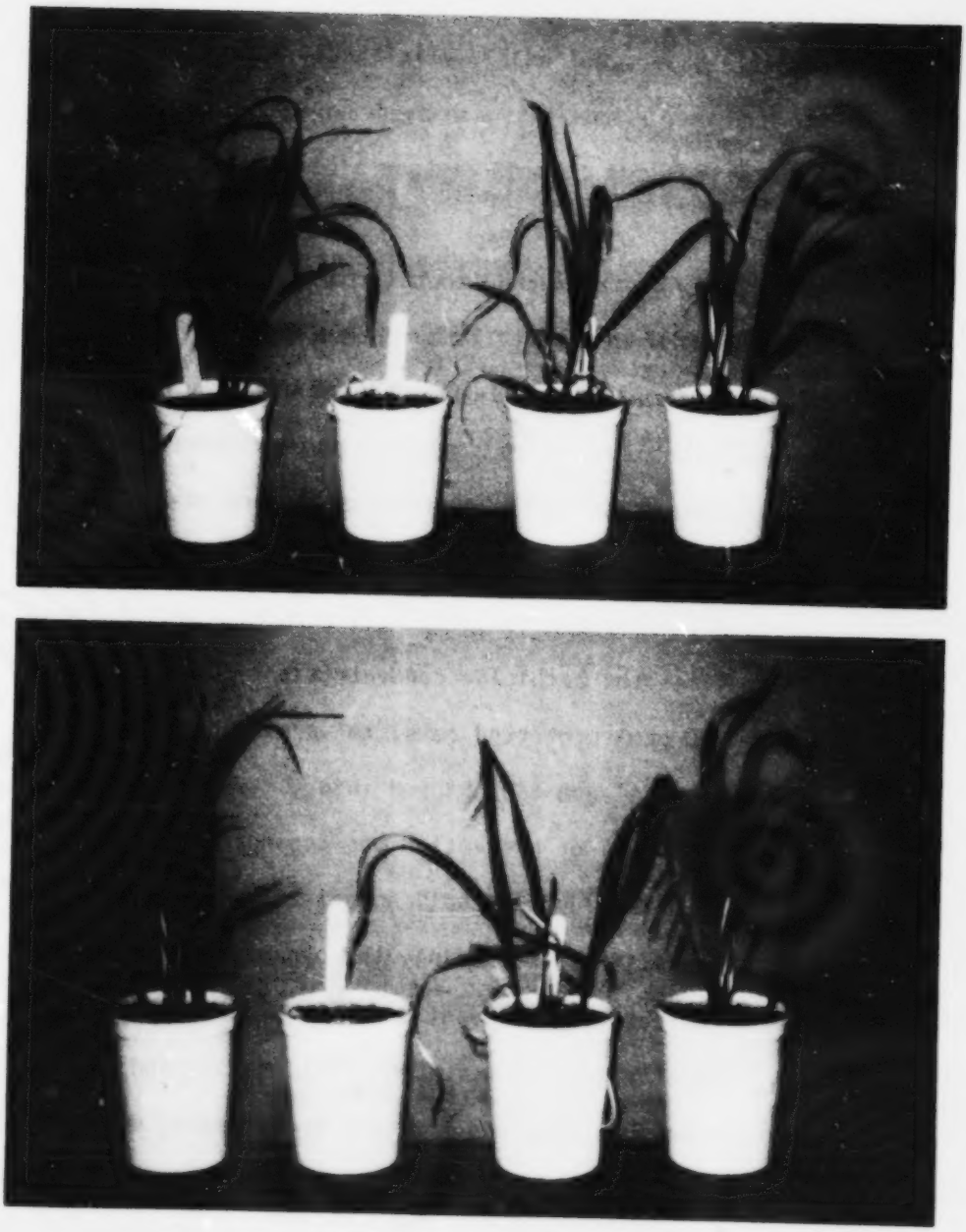


Figure 10. Photographs of plants grown in soil treated with 0.8 ppm bromacil and activated charcoal at (left to right) 0, 100, 200 and 400 times the herbicide concentration. Oats were seeded 4 weeks (upper) and 6 weeks (lower) after activated charcoal incorporation.

5. CONCLUSIONS

The conclusions that can be drawn from the results of this study are:

1. Both bromacil and tebuthiuron were more phytotoxic to oats when applied to sand or a mixture of soil+sand as compared to soil. The reduced activity of both herbicides in soil was attributed largely to their adsorption by the organic matter and clay constituents in soil.
2. Activated charcoal at rates ranging from 100 to 400 times the herbicide concentrations (0.2, 0.8 and 2.0 ppm) protected oats, to varying degrees, from bromacil and tebuthiuron injury.
3. The level of protection was dependent upon the ratio of herbicide:charcoal concentrations and soil characteristics, mainly the organic matter and clay contents. The amount of charcoal required for inactivation of herbicide residues in sand was less than that required for soil or soil+sand mixture.
4. Oats suffered more injury from bromacil or tebuthiuron residues when the plants were grown in soil maintained at field capacity (30% soil moisture content) as compared to soil where moisture level was cycled between 22.5% or 15.0% (wilting point) and field capacity.

5. Protection of oat plants from herbicide injury by charcoal, especially at the lower herbicide:charcoal concentration ratios, was slightly better under the lower moisture regimes than at the high moisture regime.
6. Protection of oats from bromacil or tebuthiuron injury by charcoal at the 1:100 herbicide:charcoal ratio, improved as the time interval between charcoal incorporation and the seeding of oats increased from 0 to 2 weeks or more. At the 1:400 ratio of herbicide:charcoal there was no effect of time interval.

6. RECOMMENDATIONS

The results of this preliminary greenhouse study indicate that activated charcoal can be effectively used for the inactivation of bromacil and tebuthiuron in soil. Further investigations are required to substantiate the findings of this study under field conditions. Field experiments should be conducted to investigate the role of soil type, herbicide:activated charcoal ratios and the time interval between charcoal application and vegetation establishment on herbicide inactivation. Studies should also be undertaken to examine the behavior and fate (dissipation, leaching and persistence) of commonly used residual herbicides in soil under Alberta conditions. Besides bromacil and tebuthiuron, other residual herbicides include chlorsulfuron (Glean®), diuron (Karmax®), picloram (Tordon®), and Atrazine (Aatrex®). Suitability of activated charcoal and other amendments such as manure and fly ash on reclamation of soils affected by various soil sterilants and residual herbicides should be investigated.

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Reclamation Research Reports

1. **RRTAC 79-2: Proceedings: Workshop on Native Shrubs in Reclamation. P.F. Ziemkiewicz, C.A. Dermott and H.P. Sims (Editors). 104 pp. No longer available.**

The Workshop was organized as the first step in developing a Native Shrub reclamation research program. The Workshop provided a forum for the exchange of information and experiences on three topics: propagation; outplanting; and, species selection. Seven papers and the results of three discussion groups are presented.

2. **RRTAC 80-1: Test Plot Establishment: Native Grasses for Reclamation. R.S. Sadasivaiah and J. Weijer. 19 pp. No longer available.**

The report details the species used at three test plots in Alberta's Eastern Slopes (one at Caw Creek Ridge and two at Cadomin). Site preparation, experimental design, and planting method are also described.

3. **RRTAC 80-3: The Role of Organic Compounds in Salinization of Plains Coal Mining Sites. N.S.C. Cameron et al. 46 pp. $10.00**

This is a literature review of the chemistry of sodic mine spoil and the changes expected to occur in groundwater.

4. **RRTAC 80-4: Proceedings: Workshop on Reconstruction of Forest Soils in Reclamation. P.F. Ziemkiewicz, S.K. Takyi and H.F. Regier (Editors). 160 pp. $10.00**

Experts in the field of forestry and forest soils report on research relevant to forest soil reconstruction and discuss the most effective means of restoring forestry capability of mined lands.

5. **RRTAC 80-5: Manual of Plant Species Suitability for Reclamation in Alberta. L.E. Watson, R.W. Parker and D.F. Polster. 2 vols, 541 pp. No longer available.**

Forty-three grass, fourteen forb, and thirty-four shrub and tree species are assessed in terms of their suitability for use in reclamation. Range maps, growth habit, propagation, tolerance, and availability information are provided.

6. **RRTAC 81-2: 1980 Survey of Reclamation Activities in Alberta. D.G. Walker and R.L. Rothwell. 76 pp. $10.00**

This survey is an update of a report prepared in 1976 on reclamation activities in Alberta, and includes research and operational reclamation, locations, personnel, etc.

7. **RRTAC 81-3: Proceedings: Workshop on Coal Ash and Reclamation. P.F. Ziemkiewicz, R. Stein, R. Leitch and G. Lutwick (Editors). 253 pp. $10.00**

Presents nine technical papers on the chemical, physical, and engineering properties of Alberta fly and bottom ashes, revegetation of ash disposal sites, and use of ash as a soil amendment. Workshop discussions and summaries are also included.

8. **RRTAC 82-1: Land Surface Reclamation: An International Bibliography. H.P. Sims and C.B. Powter. 2 vols, 292 pp. $10.00**

Literature to 1980 pertinent to reclamation in Alberta is listed in Vol. 1 and is also on the University of Alberta computing system (in a SPIRES database called RECLAIM). Vol. 2 comprises the keyword index and computer access manual.

9. **RRTAC 82-2: A Bibliography of Baseline Studies in Alberta: Soils, Geology, Hydrology and Groundwater. C.B. Powter and H.P. Sims. 97 pp. $5.00**

This bibliography provides baseline information for persons involved in reclamation research or in the preparation of environmental impact assessments. Materials, up to date as of December 1981, are available in the Alberta Environment Library.

10. **RRTAC 83-1: Soil Reconstruction Design for Reclamation of Oil Sand Tailings. Monenco Consultants Ltd. 185 pp. No longer available**

Volumes of peat and clay required to amend oil sand tailings were estimated based on existing literature. Separate soil prescriptions were made for spruce, jack pine, and herbaceous cover types. The estimates form the basis of field trials.

11. **RRTAC 83-3: Evaluation of Pipeline Reclamation Practices on Agricultural Lands in Alberta. Hardy Associates (1978) Ltd. 205 pp. No longer available.**

Available information on pipeline reclamation practices was reviewed. A field survey was then conducted to determine the effects of pipe size, age, soil type, construction method, etc. on resulting crop production.

12. **RRTAC 83-4: Proceedings: Effects of Coal Mining on Eastern Slopes Hydrology. P.F. Ziemkiewicz (Editor). 123 pp. $10.00**

Technical papers are presented dealing with the impacts of mining on mountain watersheds, their flow characteristics, and resulting water quality. Mitigative measures and priorities were also discussed.

13. **RRTAC 83-5: Woody Plant Establishment and Management for Oil Sands Mine Reclamation. Techman Engineering Ltd. 124 pp. No longer available.**

This is a review and analysis of information on planting stock quality, rearing techniques, site preparation, planting, and procedures necessary to ensure survival of trees and shrubs in oil sand reclamation.

14. **RRTAC 84-1: Land Surface Reclamation: A Review of the International Literature. H.P. Sims, C.B. Powter and J.A. Campbell. 2 vols, 1549 pp. $20.00**

Nearly all topics of interest to reclamationists including mining methods, soil amendments, revegetation, propagation and toxic materials are reviewed in light of the international literature.

15. **RRTAC 84-2: Propagation Study: Use of Trees and Shrubs for Oil Sand Reclamation. Techman Engineering Ltd. 58 pp. $10.00**

This report evaluates and summarizes all available published and unpublished information on large-scale propagation methods for shrubs and trees to be used in oil sand reclamation.

16. **RRTAC 84-3: Reclamation Research Annual Report - 1983. P.F. Ziemkiewicz. 42 pp. $5.00**

This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

17. **RRTAC 84-4: Soil Microbiology in Land Reclamation. D. Parkinson, R.M. Danielson, C. Griffiths, S. Visser and J.C. Zak. 2 vols, 676 pp. $10.00**

This is a collection of five reports dealing with re-establishment of fungal decomposers and mycorrhizal symbionts in various amended spoil types.

18. **RRTAC 85-1: Proceedings: Revegetation Methods for Alberta's Mountains and Foothills. P.F. Ziemkiewicz (Editor). 416 pp. $10.00**

Results of long-term experiments and field experience on species selection, fertilization, reforestation, topsoiling, shrub propagation and establishment are presented.

19. **RRTAC 85-2: Reclamation Research Annual Report - 1984. P.F. Ziemkiewicz. 29 pp. $5.00**

This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

20. **RRTAC 86-1: A Critical Analysis of Settling Pond Design and Alternative Technologies. A. Somani. 372 pp. $10.00**

The report examines the critical issue of settling pond design, and sizing and alternative technologies. The study was co-funded with The Coal Association of Canada.

21. **RRTAC 86-2: Characterization and Variability of Soil Reconstructed after Surface Mining in Central Alberta. T.M. Macyk. 146 pp. $10.00**

Reconstructed soils representing different materials handling and replacement techniques were characterized, and variability in chemical and physical properties was assessed. The data obtained indicate that reconstructed soil properties are determined largely by parent material characteristics and further tempered by materials handling procedures. Mining tends to create a relatively homogeneous soil landscape in contrast to the mixture of diverse soils found before mining.

22. **RRTAC 86-3: Generalized Procedures for Assessing Post-Mining Groundwater Supply Potential in the Plains of Alberta - Plains Hydrology and Reclamation Project. M.R. Trudell and S.R. Moran. 30 pp. $5.00**

In the Plains region of Alberta, the surface mining of coal generally occurs in rural, agricultural areas in which domestic water supply requirements are met almost entirely by groundwater. Consequently, an important aspect of the capability of reclaimed lands to satisfy the needs of a residential component is the post-mining availability of groundwater. This report proposes a sequence of steps or procedures to identify and characterize potential post-mining aquifers.

23. **RRTAC 86-4: Geology of the Battle River Site: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze, R. Li, M. Fenton and S.R. Moran. 86 pp. $10.00**

This report summarizes the geological setting of the Battle River study site. It is designed to provide a general understanding of geological conditions adequate to establish a framework for hydrogeological and general reclamation studies. The report is not intended to be a detailed synthesis such as would be required for mine planning purposes.

24. **RRTAC 86-5: Chemical and Mineralogical Properties of Overburden: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze. 71 pp. $10.00**

This report describes the physical and mineralogical properties of overburden materials in an effort to identify individual beds within the bedrock overburden that might be significantly different in terms of reclamation potential.

25. **RRTAC 86-6: Post-Mining Groundwater Supply at the Battle River Site: Plains Hydrology and Reclamation Project. M.R. Trudell, G.J. Sterenberg and S.R. Moran. 49 pp. $5.00**

The report deals with the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The study area is in the Battle River Mining area in east-central Alberta.

26. **RRTAC 86-7: Post-Mining Groundwater Supply at the Highvale Site: Plains Hydrology and Reclamation Project. M.R. Trudell. 25 pp. $5.00**

This report evaluates the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The study area is the Highvale mining area in west-central Alberta.

27. **RRTAC 86-8: Reclamation Research Annual Report - 1985. P.F. Ziemkiewicz. 54 pp. $5.00**

This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

28. **RRTAC 86-9: Wildlife Habitat Requirements and Reclamation Techniques for the Mountains and Foothills of Alberta. J.E. Green, R.E. Salter and D.G. Walker. 285 pp. $10.00**

This report presents a review of relevant North American literature on wildlife habitats in mountain and foothills biomes, reclamation techniques, potential problems in wildlife habitat reclamation, and potential habitat assessment methodologies. Four biomes (Alpine, Subalpine, Montane, and Boreal Uplands) and 10 key wildlife species (snowshoe hare, beaver, muskrat, elk, moose, caribou, mountain goat, bighorn sheep, spruce grouse, and white-tailed ptarmigan) are discussed. The study was co-funded with The Coal Association of Canada.

29. **RRTAC 87-1: Disposal of Drilling Wastes. L.A. Leskiw, E. Reinl-Dwyer, T.L. Dabrowski, B.J. Rutherford and H. Hamilton. 210 pp. No longer available.**

Current drilling waste disposal practices are reviewed and criteria in Alberta guidelines are assessed. The report also identifies research needs and indicates mitigation measures. A manual provides a decision-making flowchart to assist in selecting methods of environmentally safe waste disposal.

30. **RRTAC 87-2: Minesoil and Landscape Reclamation of the Coal Mines in Alberta's Mountains and Foothills. A.W. Fedkenheuer, L.J. Knapik and D.G. Walker. 174 pp. $10.00**

This report reviews current reclamation practices with regard to site and soil reconstruction and re-establishment of biological productivity. It also identifies research needs in the Mountain-Foothills area. The study was co-funded with The Coal Association of Canada.

31. **RRTAC 87-3: Gel and Saline Drilling Wastes in Alberta: Workshop Proceedings. D.A. Lloyd (Compiler). 218 pp. $10.00**

Technical papers were presented which describe: mud systems used and their purpose; industrial constraints; government regulations, procedures and concerns; environmental considerations in waste disposal; and toxic constituents of drilling wastes. Answers to a questionnaire distributed to participants are included in an appendix.

32. **RRTAC 87-4: Reclamation Research Annual Report - 1986. 50 pp. $5.00**

This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

33. **RRTAC 87-5: Review of the Scientific Basis of Water Quality Criteria for the East Slope Foothills of Alberta. Beak Associates Consulting Ltd. 46 pp. $10.00**

The report reviews existing Alberta guidelines to assess the quality of water drained from coal mine sites in the East Slope Foothills of Alberta. World literature was reviewed within the context of the East Slopes environment and current mining operations. The ability of coal mine operators to meet the various guidelines is discussed. The study was co-funded with The Coal Association of Canada.

34. **RRTAC 87-6: Assessing Design Flows and Sediment Discharge on the Eastern Slopes. Hydrocon Engineering (Continental) Ltd. and Monenco Consultants Ltd. 97 pp. $10.00**

The report provides an evaluation of current methodologies used to determine sediment yields due to rainfall events in well-defined areas. Models are available in Alberta to evaluate water and sediment discharge in a post-mining situation. SEDIMOT II (Sedimentology Disturbed Modelling Techniques) is a single storm model that was developed specifically for the design of sediment control structures in watersheds disturbed by surface mining and is well suited to Alberta conditions. The study was co-funded with The Coal Association of Canada.

35. **RRTAC 87-7: The Use of Bottom Ash as an Amendment to Sodic Spoil. S. Fullerton. 83 pp. No longer available.**

The report details the use of bottom ash as an amendment to sodic coal mine spoil. Several rates and methods of application of bottom ash to sodic spoil were tested to determine which was the best at reducing the effects of excess sodium and promoting crop growth. Field trials were set up near the Vesta mine in East Central Alberta using ash readily available from a nearby coal-fired thermal generating station. The research indicated that bottom ash incorporated to a depth of 30 cm using a subsoiler provided the best results.

36. **RRTAC 87-8: Waste Dump Design for Erosion Control. R.G. Chopiuk and S.E. Thornton. 45 pp. $5.00**

This report describes a study to evaluate the potential influence of erosion from reclaimed waste dumps on downslope environments such as streams and rivers. Sites were selected from coal mines in Alberta's mountains and foothills, and included resloped dumps of different configurations and ages, and having different vegetation covers. The study concluded that the average annual amount of surface erosion is minimal. As expected, erosion was greatest on slopes which were newly regraded. Slopes with dense grass cover showed no signs of erosion. Generally, the amount of erosion decreased with time, as a result of initial loss of fine particles, the formation of a weathered surface, and increased vegetative cover.

37. **RRTAC 87-9: Hydrogeology and Groundwater Chemistry of the Battle River Mining Area. M.R. Trudell, R.L. Faught and S.R. Moran. 97 pp. No longer available.**

This report describes the premining geologic conditions in the Battle River coal mining area including the geology as well as the groundwater flow patterns, and the groundwater quality of a sequence of several water-bearing formations extending from the surface to a depth of about 100 metres.

38. **RRTAC 87-10: Soil Survey of the Plains Hydrology and Reclamation Project - Battle River Project Area. T.M. Macyk and A.H. MacLean. 62 pp. plus 8 maps. $10.00**

The report evaluates the capability of post-mining landscapes and assesses the changes in capability as a result of mining, in the Battle River mining area. Detailed soils information is provided in the report for lands adjacent to areas already mined as well as for lands that are destined to be mined. Characterization of the reconstructed soils in the reclaimed areas is also provided. Data were collected from 1979 to 1985. Eight maps supplement the report.

39. **RRTAC 87-11: Geology of the Highvale Study Site: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze. 78 pp. $10.00**

The report is one of a series that describes the geology, soils and groundwater conditions at the Highvale Coal Mine study site. The purpose of the study was to establish a summary of site geology to a level of detail necessary to provide a framework for studies of hydrogeology and reclamation.

40. **RRTAC 87-12: Premining Groundwater Conditions at the Highvale Site. M.R. Trudell and R. Faught. 83 pp. $10.00**

This report presents a detailed discussion of the premining flow patterns, hydraulic properties, and isotopic and hydrochemical characteristics of five layers within the Paskapoo Geological Formation, the underlying sandstone beds of the Upper Horseshoe Canyon Formation, and the surficial glacial drift.

41. **RRTAC 87-13: An Agricultural Capability Rating System for Reconstructed Soils. T.M. Macyk. 27 pp. $5.00**

This report provides the rationale and a system for assessing the agricultural capability of reconstructed soils. Data on the properties of the soils used in this report are provided in RRTAC 86-2.

42. **RRTAC 88-1: A Proposed Evaluation System for Wildlife Habitat Reclamation in the Mountains and Foothills Biomes of Alberta: Proposed Methodology and Assessment Handbook. T.R. Eccles, R.E. Salter and J.E. Green. 101 pp. plus appendix. $10.00**

The report focuses on the development of guidelines and procedures for the assessment of reclaimed wildlife habitat in the Mountains and Foothills regions of Alberta. The technical section provides background documentation including a discussion of reclamation planning, a listing of reclamation habitats and associated key wildlife species, conditions required for development, recommended revegetation species, suitable reclamation techniques, a description of the recommended assessment techniques and a glossary of basic terminology. The assessment handbook section contains basic information necessary for evaluating wildlife habitat reclamation, including assessment scoresheets for 15 different reclamation habitats, standard methodologies for measuring habitat variables used as assessment criteria, and minimum requirements for certification. This handbook is intended as a field manual that could potentially be used by site operators and reclamation officers. The study was co-funded with The Coal Association of Canada.

43. **RRTAC 88-2: Plains Hydrology and Reclamation Project: Spoil Groundwater Chemistry and its Impacts on Surface Water. M.R. Trudell (Compiler). 135 pp. $10.00**

Two reports comprise this volume. The first "Chemistry of Groundwater in Mine Spoil, Central Alberta," describes the chemical make-up of spoil groundwater at four mines in the Plains of Alberta. It explains the nature and magnitude of changes in groundwater chemistry following mining and reclamation. The second report, "Impacts of Surface Mining on Chemical Quality of Streams in the Battle River Mining Area," describes the chemical quality of water in streams in the Battle River mining area, and the potential impact of groundwater discharge from surface mines on these streams.

44. **RRTAC 88-3: Revegetation of Oil Sands Tailings: Growth Improvement of Silver-berry and Buffalo-berry by Inoculation with Mycorrhizal Fungi and N_2-Fixing Bacteria. S. Visser and R.M. Danielson. 98 pp. $10.00**

The report provides results of a study: (1) To determine the mycorrhizal affinities of various actinorrhizal shrubs in the Fort McMurray, Alberta region; (2) To establish a basis for justifying symbiont inoculation of buffalo-berry and silver-berry; (3) To develop a growing regime for the greenhouse production of mycorrhizal, nodulated silver-berry and buffalo-berry; and, (4) To conduct a field trial on reconstructed soil on the Syncrude Canada Limited oil sands site to critically evaluate the growth performance of inoculated silver-berry and buffalo-berry as compared with their uninoculated counterparts.

45. **RRTAC 88-4: Plains Hydrology and Reclamation Project: Investigation of the Settlement Behaviour of Mine Backfill. D.R. Pauls (compiler). 135 pp. $10.00**

This three part volume covers the laboratory assessment of the potential for subsidence in reclaimed landscapes. The first report in this volume, "Simulation of Mine Spoil Subsidence by Consolidation Tests," covers laboratory simulations of the subsidence process particularly as it is influenced by resaturation of mine spoil. The second report, "Water Sensitivity of Smectitic Overburden: Plains Region of Alberta," describes a series of laboratory tests to determine the behaviour of overburden materials when brought into contact with water. The report entitled "Classification System for Transitional Materials: Plains Region of Alberta," describes a lithological classification system developed to address the characteristics of the smectite rich, clayey transition materials that make up the overburden in the Plains of Alberta.

46. **RRTAC 88-5: Ectomycorrhizae of Jack Pine and Green Alder: Assessment of the Need for Inoculation, Development of Inoculation Techniques and Outplanting Trials on Oil Sand Tailings. R.M. Danielson and S. Visser. 177 pp. $10.00**

The overall objective of this research was to characterize the mycorrhizal status of Jack Pine and Green Alder which are prime candidates as reclamation species for oil sand tailings and to determine the potential benefits of mycorrhizae on plant performance. This entailed determining the symbiont status of container-grown nursery stock and the quantity and quality of inoculum in reconstructed soils, developing inoculation techniques and finally, performance testing in an actual reclamation setting.

47. **RRTAC 88-6: Reclamation Research Annual Report - 1987. Reclamation Research Technical Advisory Committee. 67 pp. No longer available.**

This annual report describes the expenditure of $500,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

48. **RRTAC 88-7: Baseline Growth Performance Levels and Assessment Procedure for Commercial Tree Species in Alberta's Mountains and Foothills. W.R. Dempster and Associates Ltd. 66 pp. $5.00**

Data on juvenile height development of lodgepole pine and white spruce from cut-over or burned sites in the Eastern Slopes of Alberta were used to define reasonable expectations of early growth performance as a basis for evaluating the success of reforestation following coal mining. Equations were developed predicting total seedling height and current annual height increment as a function of age and elevation. Procedures are described for applying the equations, with further adjustments for drainage class and aspect, to develop local growth performance against these expectations. The study was co-funded with The Coal Association of Canada.

49. **RRTAC 88-8: Alberta Forest Service Watershed Management Field and Laboratory Methods. A.M.K. Nip and R.A. Hursey. 4 Sections, various pagings. $10.00**

Disturbances such as coal mines in the Eastern Slopes of Alberta have the potential for affecting watershed quality during and following mining. The collection of hydrometric, water quality and hydrometeorologic information is a complex task. A variety of instruments and measurement methods are required to produce a record of hydrologic inputs and outputs for a watershed basin. There is a growing awareness and recognition that standardization of data acquisition methods is required to ensure data comparability, and to allow comparison of data analyses. The purpose of this manual is to assist those involved in the field of data acquisition by outlining methods, practices and instruments which are reliable and recognized by the International Organization for Standardization.

50. **RRTAC 88-9: Computer Analysis of the Factors Influencing Groundwater Flow and Mass Transport in a System Disturbed by Strip Mining. F.W. Schwartz and A.S. Crowe. 78 pp. $10.00**

Work presented in this report demonstrates how a groundwater flow model can be used to study a variety of mining-related problems such as declining water levels in areas around the mine as a result of dewatering, and the development of high water tables in spoil once resaturation is complete. This report investigates the role of various hydrogeological parameters that influence the magnitude, timing, and extent of water level changes during and following mining at the regional scale. The modelling approach described here represents a major advance on existing work.

51. **RRTAC 88-10: Review of Literature Related to Clay Liners for Sump Disposal of Drilling Wastes. D.R. Pauls, S.R. Moran and T. Macyk. 61 pp. $5.00**

The report reviews and analyses the effectiveness of geological containment of drilling waste in sumps. Of particular importance was the determination of changes in properties of clay materials as a result of contact with highly saline brines containing various organic chemicals.

52. **RRTAC 88-11: Highvale Soil Reconstruction Project: Five Year Summary. D.N. Graveland, T.A. Oddie, A.E. Osborne and L.A. Panek. 104 pp. $10.00**

This report provides details of a five year study to determine a suitable thickness of subsoil to replace over minespoil in the Highvale plains coal mine area to ensure return of agricultural capability. The study also examined the effect of slope and aspect on agricultural capability. This study was funded and managed with industry assistance.

53. **RRTAC 88-12: A Review of the International Literature on Mine Spoil Subsidence. J.D. Scott, G. Zinter, D.R. Pauls and M.B. Dusseault. 36 pp. $10.00**

The report reviews available engineering literature relative to subsidence of reclaimed mine spoil. The report covers methods for site investigation, field monitoring programs and lab programs, mechanisms of settlement, and remedial measures.

54. **RRTAC 89-1: Reclamation Research Annual Report - 1988. 74 pp. $5.00**

This annual report describes the expenditure of $280,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

55. **RRTAC 89-2: Proceedings of the Conference: Reclamation, A Global Perspective. D.G. Walker, C.B. Powter and M.W. Pole (Compilers). 2 Vols., 854 pp. $10.00**

Over 250 delegates from all over the world attended this conference held in Calgary in August, 1989. The proceedings contains over 85 peer-reviewed papers under the following headings: A Global Perspective; Northern and High Altitude Reclamation; Fish & Wildlife and Rangeland Reclamation; Water; Herbaceous Revegetation; Woody Plant Revegetation and Succession; Industrial and Urban Sites; Problems and Solutions; Sodic and Saline Materials; Soils and Overburden; Acid Generating Materials; and, Mine Tailings.